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(54) **Tactile pressure sensor.**

(57) A sensitive, durable, high resolution tactile sensor (10) particularly suited for use as a robot end effector in an automated manufacturing process. The tactile sensor (10) has an array of pressure sensing sites (S1, S2...) provided by a series of current emitter electrodes (20) surrounded by a series of companion current collector electrodes (21) both of which engage a rough conductive layer (23) carried on the underside f a resilient platen (16). The emitters (20) are electrically connected together in parallel rows, and the collectors (21) are electrically connected together in parallel columns above and across the rows. The emitters (20) and collectors (21) are electrically insulated from one another as are the rows and columns. When the platen (16) engages an object (P) to apply pressure at one of the sites, and a positive voltage is applied to an emitter electrode, current flows from the emitter electrode (20) and through the conductive layer (23) to the companion collector electrode (21) from which it is collected and measured. Cross-multiplexing circuitry (36 etc) scans the rows and columns periodically to provide a read ut of both the location and magnitude of appli d pressure.

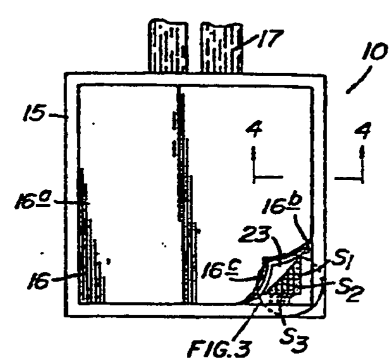

FIG. 2

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TACTILE SENSOR

TITLE MODIFIED
see front page

The present invention relates to tactile sensors, and more particularly, the present invention relates to tactile sensors which are particularly suited for use with automated equipment of various types, including robots and robot end effectors.

Increasingly sophisticated types of automated equipment, such as robots, are being used in a wide variety of manufacturing operations, including inspection, identification, pick and place procedures, assembly procedures, and the like. To enable robotic equipment to grip parts in a particular manner without damaging the same, some robots are being equipped with end effectors, or jaws, having tactile sensors which give the end effectors a certain degree of feelability. Other automated equipment utilizes work surface mounted sensors to provide sensory feedback to assist in the manipulation of parts thereon. The tactile sensors are electrically connected to suitable circuitry associated with the equipment to enable various parameters of a part, including its size and shape, and the force exerted on the part, to be detected.

Tactile sensors whi h operate on various principles are known. For instance, a satisfactory optoelectric tactile sensor manufactured by Lord Corporation of Erie, Pennsylvania has a flexible platen with an array of depending projections which cooperate with light emitters and receivers disposed on opposite sides of the projections to provide electrical outputs when the portion of the platen superadjacent the projection is deflected and light transmission between the emitters and receivers is modulated by movement of the projections.

A tactile sensor which utilizes a pressure responsive electrically conductive elastomer is disclosed in U. S. Pat. No. 4,014,217 to Lagasse et al. This sensor has a series of annular electrodes which surround a series of central electrodes and which cooperate with a doped elastomeric member to produce a readout when current fields, established in the elastomeric member by the electrodes, are altered by applied pressure.

One form of tactile sensor which incorporates discrete semi-conductive sensing sites is disclosed in U. S. Pat. No. 4,492,949 to Peterson. This sensor includes a compressible panel having a series of pressure responsive electrically conductive posts distributed in an array between a series of rows of partially exposed conductors embedded in a flexible member overlying the panel and a series of columns of partially exposed conductors embedded in a base underlying the panel orthogonal to the rows. The posts are located at the intersections of the rows and

columns so that when pressure is appli d superadjacent each post, its electrical resistance decreases, permitting current to flow from a row to a column. The rows and columns are sequentially scanned by suitable cross-multiplexing circuitry to provide a readout of the location and magnitude of applied pressure.

The utilization of cross-multiplexing electronic circuitry in combination with tactile sensors, such as described in the above-referenced patent to Peterson, the disclosure of which is incorporated by reference herein, provides the advantage of enabling the density of sensing sites to be increased and thereby to increase the resolution of the sensor. A limiting factor in achieving high resolution, however, has been the introduction of electrical cross-talk, or phantom switching phenomenon, in cross multiplexed sensor systems. To overcome this problem, some sensors have diodes located at each sensing site, such as disclosed in U. S. Pat. No. 4,481,815 to Overton.

For a more complete review of the state of the art with respect to tactile sensing using conductive elastomers, reference is made to the following articles: Peter and Cholakis, "Tactile Sensing For End-Effectors", Barry Wright Corporation, Watertown, Massachusetts; Marc H. Raibert and John E. Tanner, "Design And Implementation Of A VLSI Tactile Sensing Computer", The International Journal of Robotics Research, Volume 1, No. 3, Fall 1982; William Daniel Hillis, "Active Touch Sensing", Massachusetts Institute of Technology Artificial Intelligence Laboratory, April 1981, AI Memo 629, pp. 1-37; and Purbrick, John A., "A Force

Transducer Employing Conductive Silicone Rubber", Proc. 1st, Robot Vision and S nsors Conf., IFS Pubs., Ltd., Kempston, Bedford, England, 1980, pp. 73-80.

Prior art tactile sensors have various drawbacks. Those utilizing optoelectric principles are expensive to manufacture. Those utilizing electrically conductive elastomers have low sensitivity and a proclivity to wear because the conductive particles doping the elastomer affect adversely its mechanical properties. Those sensors utilizing discrete pressure sensitive posts in a cross-multiplexing array, and those incorporating diodes, are expensive to manufacture. Furthermore, each of the prior art sensors has limited resolution and sensitivity, and none is as durable and inexpensive to manufacture as desired.

With the foregoing in mind, a primary object of the present invention is to provide a novel tactile sensor which overcomes the limitations of known tactile sensors.

Another object of the present invention is to provide an improved tactile sensor which provides both high resolution and sensitivity in a large field.

A further object of the present invention is to provide a rugged tactile sensor which is relatively inexpensive to manufacture.

As a still further object, the present invention provides a method and apparatus for accurately sensing pressure distribution over a relatively large area with a minimum of components.

As yet another object, the present invention provides a tactile sensor which operates in a cross-multiplexing mode with a minimum of interference caused by electrical cross-talk and phantom switching.

More specifically, the present invention provides tactile sensing apparatus which functions in a novel manner to provide an accurate readout of both the magnitude and distribution of pressure applied to a sensing surface.

The sensor comprises a resilient platen having an upper surface adapted to be contacted by an object and a lower surface overlying a plurality of spaced pressure sensing sites. Each site includes emitter electrode means and companion collector electrode means surrounding the emitter electrode means in spaced relation therewith. Flexible conductive means on the lower surface of the platen cooperates with the emitter and collector means to cause substantially all of the current emitted by an emitter means to be collected by its companion collector means when the platen is deflected downwardly superadjacent the sensing site and a voltage differential is applied across the emitter and collector means.

Preferably, the sensing sites are provided by a series of current emitter electrodes electrically interconnected in a row by a bus bar and a series of current collector electrodes surrounding the current emitter electrodes and electrically connected in a column by another bus bar disposed above and across the row. The emitter

electrodes are electrically insulated from their companion collector electrodes, and the bus bars defining the rows and columns are electrically isolated from one another. The rows are provided on the underside of an insulated panel, and the columns are provided on the topside thereof coplanar with the emitter electrodes. A resilient platen overlies the array of emitter and collector electrodes and has on its underside a thin, rough coating of electrically conductive material engaging the emitter and collector electrodes. A means is provided for simultaneously supplying a positive voltage to a selected one of the rows of emitter electrodes and a lower voltage to the columns for causing current to flow at a site under pressure from one of the emitters at such site, through the coating, and to the companion collector for collection and measurement by multiplexing circuitry which repeats these steps periodically to produce a readout of both the location and magnitude of applied pressure.

The foregoing and other objects, features and advantages of the present invention should become apparent from the following description when taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a fragmentary perspective view illustrating a few different applications for a tactile sensor embodying the present invention;

FIG. 2 is a plan view of a tactile sensor embodying the present invention with a portion of its

sensing surface peel d back to reveal certain interior construction details;

FIG. 3 is a greatly enlarged fragmentary plan view of the revealed portion of the sensor illustrated in FIG. 2;

FIG. 4 is an enlarged fragmentary cross-sectional view taken on line 4-4 of FIG. 2;

FIG. 5 is a greatly enlarged sectional view of the area contained within the circle illustrated in FIG. 4;

FIG. 6 is an enlarged somewhat schematic fragmentary plan view of certain sensor elements;

FIG. 7 is a sectional view taken on line 7-7 of FIG. 6;

FIG. 8 is an electrical schematic diagram illustrating certain principles of operation of the present invention;

FIG. 9 is an enlarged fragmentary plan view of a portion of a modified embodiment of the present invention; and

FIG. 10 is a plan view of another modified embodiment of the present invention.

Referring now to the drawings, FIG. 1 illustrates a tactile sensor 10 which embodies the present invention. The tactile sensor 10 may be supported on a work surface 11 for sensing the orientation of a part P in an assembly operation; or, a smaller version 10' thereof may be mounted on one or both movable elements 12 of an end effector 13 mounted at the end of a robot arm 14 to enable the part P to

be gripped in the proper manner with the proper amount of pressure.

As discussed heretofore, known tactile sensors are limited in resolution, sensitivity, durability and manufacturability. In addition, known tactile sensors utilizing cross-multiplexing techniques to maximize field size and minimize components have been plagued by electrical cross-talk and phantom switching problems which may be described briefly as the proclivity for electrical activity at one pressure sensing site to produce an output at an adjacent pressure sensing site. Attempts to overcome these problems either by complex mechanical structures or by connecting electrical components in the structure have not been entirely satisfactory.

The tactile sensor of the present invention overcomes the limitations of known prior art tactile sensors. For instance, it has high spatial resolution and fine sensitivity over a relatively large sensing area. In addition, it is durable and capable of being manufactured readily. Furthermore, tactile sensing apparatus embodying the present invention functions accurately to sense objects by eliminating electrical cross-talk among its various sensing sites.

Referring again to the drawings, and particularly to FIG. 2 thereof, the tactile sensor 10 of the present invention comprises a frame 15 which may be of any shape but which, in the illustrated embodiment, is square. A resilient platen 16 is mounted to the frame 15 by a layer of adhesive extending around its peripheral margin. The platen

16 has an obverse surface, or topside 16a, adapted to engage an obj ct, such as the part P illustrated in FIG. 1, and a reverse surface, or underside 16b. One or more wiring harnesses, such as the wiring harness 17, are provided for connecting the sensor 10 to suitable circuitry in a manner to be described.

The tactile sensor 10 has high resolution. To this end, an array of closely spaced pressure sensing sites, such as the sites S_1, S_2 and S_3 (indicated within the perimeter of the circle denominated "FIG. 3" in FIG. 2) are provided within the frame 15 underneath the platen 16. The field, or area, occupied by the sensing sites S_1 - S_3 is substantially square and coextensive with the area of the platen 16. Preferably, the sensing sites S_1 - S_3 are located at equally spaced horizontal and vertical intervals having, by way of example, center to center spacings on the order of less than about 0.100 inches, and more preferably, about 0.080 inches, thereby enabling 6400 sensing sites to be arranged in a field of less than 40 square inches for a sensing site density in excess of 150 sites per square inch.

According to the present invention, pressure sensing is accomplished by powering the emitter electrodes at the sites and measuring the current collected by their respective companion collector electrodes. As best seen in FIG. 6, each sensing site, such as the central site S_2 comprises an emitter electrode 20 surrounded by a companion collector electrode 21 disposed coplanar therewith and spaced therefrom by a continuous annular gap 22 of a very narrow width, such as 0.008 inches. A continuous, flexible

conductive coating, or layer, 23 (FIG. 5) is disp sed n substantially the entire undersurface 16b of the platen 16, except at its peripheral margin 16c, to provide omnidirectional resistivity on the platen undersurface 16c and to cooperate with the the platen 16 to provide a plurality of microprotrusions forming an asperity, or roughness, on its undersurface 16b. Thus, when the platen 16 is deflected downwardly into engagement with electrodes 20, 21 at an underlying site, such as the site S_2, the layer 23 bridges the gap 22 between the electrodes and conducts current from emitter electrode 20 to collector electrode 21.

The magnitude of the current conducted from emitter electrode 20 to collector electrode 21 is a function of both fixed and variable parameters. The fixed parameters include: (1) the lateral resistance of layer 23, i.e. along the platen 16, which is relatively great when (as in the preferred illustrative embodiment) the layer is very thin; (2) the relative sizes in a lateral direction of the narrow gap 22 and the relatively wide collector electrode 21; and (3) the lateral dimensions of the gaps or spaces 25a, 25b between the collector electrode and any adjacent collector electrode, such as the gap 25a between the central collector electrode 21 and the collector electrode 21a of the right hand sensitive site illustrated in FIG. 7. A variable parameter affecting the magnitude of the current conducted from emitter electrode 20 to collector electrode 21 is due to the microprotrusions that impart an asperity, or roughness, to the layer 23.

When the pressure effecting engagement between layer 23 and the underlying pair of emitter and collector electrodes is small, the microprotrusions provide only a small area of contact between the layer and the electrodes. The resistance to current flow from emitter electrode 20 to collector electrode 21 is therefore high, and the current flow is low. A greater pressure upon platen 16 increases the area of contact of the layer with the electrodes 20, 21, thus decreasing the resistance and increasing the current flow from emitter 20 to collector 21. By monitoring the current received by the collector 21 at a particular site, the pressure upon such site can be ascertained and a grey scale, or analog, output signal produced, provided that such electrode receives only current from its companion emitter electrode 20 and not also, or instead, from an emitter electrode at some other site.

To satisfy the foregoing condition, to prevent electrical cross-talk among the various sensitive sites, and to maximize the available current signal strength, substantially all of the current received by layer 23 from an emitter electrode at a particular site is transmitted to and into the companion collector electrode at such site. No significant amount of such current is transmitted to any other site. This results in highly desirable site localization of electrical activity of the emitted current which, in part, is attributable to the emitter electrode at each site being totally encircled or surrounded by its annular companion collector electrode. Site localization of electrical activity is also attributable to the differing

resistances to current fl w that are present within and between the sensitive sites by reason of the component size and spacing parameters previously described.

The differing resistances to current flow are schematically illustrated in FIG. 8, to which reference is now made. Resistances R_1, R_3 and R_5 represent variable ones whose magnitude is a function of the pressure imposed upon the platen 16. The magnitude of resistance R_3 is also dependent upon the lateral, or radial, dimension of collector electrode 21, as is the resistance R_5. Resistance R_2 has a magnitude determined by the resistivity of layer 23, by the lateral dimensions of the gap 22, and by the pressure applied to that portion of platen 16 overlying electrodes 20, 21. The magnitude of resistance R_4 is dependent upon the resistivity of layer 23, upon the size of the lateral gap or spacing between adjacent collector electrodes, at any adjacent sensitive site, such as the gap 25a between the collector electrode 21 and the collector electrode 21a, and upon the pressure applied to the overlying platen 16 at the sensitive site in question and at the adjacent site or sites. The resistance R_3 under all operating conditions is much less than the sum of the resistances R_4 and R_5, i.e. $R_3 \ll R_4 + R_5$.

Thus, when emitter electrode 20 is energized from a suitable power source 30, and a pressure (such as indicated in FIG. 7) is applied upon the portion of the platen 16 overlying such electrode 20 and its companion collector electrode 21, substantially all of the current conducted from emitter 20 follows the path that includes the

resistances R_1, R_2 and R_3, extending t collector 21, rather than any alternative path (such as the illustrated ne which includes resistances R_1, R_2, R_4 and R_5) extending to an adjacent sensitive site. In other words, the resistance between the emitter 20 and an adjacent non-companion collector 21a, and the resistance between the emitter 20a and an adjacent non-companion collector 21, is greater than the resistance between either emitter electrode 20 or 20a and its respective companion collector electrode 21 or 21a. Amplifier 32 monitors current received by collector 21 and provides an output signal voltage representative of the magnitude of the applied pressure. The amplifiers 31-33 also function in a conventional manner to apply virtual ground electrical potential to their respective collectors.

In order to enable the location of pressure application to be determined, and to simplify the sensor design and support circuitry, the sensor 10 is designed to be operated in conjunction with cross-multiplexing means, such as the type of circuitry disclosed in the above referenced Peterson patent, the disclosure of which is incorporated by reference herein. To this end, the emitter electrodes, such as the electrodes, 20, 20a and 20b, are each electrically interconnected to a bus bar 35 (FIG. 3), provided on the underside of an insulated panel 38. In the present instance, such connection is provided by transverse pins, such as the hollow pin 39 (FIG. 5) projecting upwardly from the bus bar 35 through the panel 38. A series of bus bars, such as the bars 36 and 37, extend in rows in spaced parallel relation with the bar 35 in the manner illustrated

in FIG. 3. The bus bars 35 - 37 are electrically isolated from ne another along their lengths by small air gaps 40, 41 to define horizontal rows of electrically interconnected emitter electrodes.

The collector electrodes, such as the electrodes 21a, 21 and 21b, are electrically interconnected on the topside of the panel 38 by means of conductive bus bars 42, 43 and 44 which form the electrodes, such as in the manner the electrode 21 of sensing site S_2 (FIG. 6) is formed integral with, and thus connected to, the bus bar 43. The bus bars 42 - 44 are arranged in parallel relation in vertical columns and are separated laterally from one another along their lengths by small air gaps 45, 46, respectively providing electrical isolation therebetween. The collector bus bars 42 - 44 are disposed at right angles to the emitter bus bars 35 - 37, and the sensing sites S_1 - S_3 are located at the intersections thereof.

The insulating air gaps 45 and 46 between the columnar bus bars 42 - 44, and the corresponding air gaps 40 and 41 between the rows of bus bars 35 - 37 are small, each gap being on the order of .008 inches. Preferably, the rows and columns of bus bars, such as the bus bars 42 - 44, are provided with extensions 42a - 44a which terminate in plated pin holes in the margin of the panel 38 to permit the wiring harnesses 17 to be connected by conventional connectors. The reverse surface of the platen 16 is left uncoated around its peripheral margin at 16c to provide electrical insulation above the bus bar extensions and pin connections. The emitters, collectors and their respective bus bars are

pr vided n the panel 38 by conventional printed circuit manufacturing proc sses which involve plating through hol s in the panel 38 to provide the emitter electrode pins and then etching away conductive material to provide the referenced air gaps and to define the bus bars and the current emitter and collector electrodes.

The cross-multiplexing means utilized in the present invention applies a positive voltage to a selected one of the bus bar rows, such as the bus bar 36, and applying a lower voltage, preferably at virtual ground potential, to each of the bus bar columns, such as the bus bars 42, 43 and 44 to establish a pressure responsive current flow path through the conductive layer 23 between each emitter electrode of the selected bus bar and its companion collector electrode, such as provided at sensing site S_2. Current flow in a selected one of the columnar bus bars, such as 43, is measured to provide an electrical signal representative of any applied pressure at each site along the active emitter bus bar row. These steps are repeated for each column, row by row, the current collected and measured, and appropriate readouts produced.

While all of the columns may be held to virtual ground potential during multiplexing, only three need be. For instance, only the pair of columns 42 and 44 alongside the column 43 being read must be held at ground potential. Therefore, groups of three columns may be scanned across each row when activated.

The emitter and collector electrodes may be arranged in a pattern such as illustrated in th portion of

a sens r 110 f FIG. 9 wherein a common collector electrode, such as the electrode 121, surrounds a group of thr e emitter electrodes, such as the emitter electrodes 120, 120a, and 120b. With this arrangement, when voltage is applied to one of the rows, such as the row 135 connected to the upper emitter electrode 120b, current collected by the emitter electrode 121 is representative of the pressure applied to the platen 116 superadjacent the emitter electrode 120b. By activating each row sequentially and measuring current flow from each column while a row is activated, pressure applied at each sensing site may be determined.

If desired, the rows and columns of emitter electrodes and collector electrodes may be arranged in various other patterns than described heretofore, such as the circular pattern illustrated in the modified sensor 210 of FIG. 10 wherein the rows 235 - 237 extend radially and the columns 242 - 244 extend circumferentially about an open center.

The tactile sensor of the present invention is capable of being manufactured readily. To this end, the platen 16 is fabricated from a sheet of relatively soft elastomeric material, such as natural or synthetic rubber. The underside of the platen 16 is spray coated with an electrically conductive polyurethane which comprises conductive particles in an elastic carrier, such as H322 and L300 manufactured by the Chemical Products Group of Lord Corporation, Erie, Pennsylvania. The spray should deposit the polyurethane in as thin a coating as possible, and

preferably the c ating should have a thickness f less than about one mil. The microprotrusions pr vided by the coating should have a roughness which is less than that which w uld be visible to the naked eye or palpable by touch.

The sensor 10 can be assembled readily. To this end, as best seen in FIG. 4, the panel 38 is mounted beneath the conductive coating 23 on the underside of the platen 16 by a rigid insulating board 50 which underlies the panel 38 and extends substantially coextensively with the area of the platen 16. The insulating board 50 is supported on an inner frame 51 which, in turn, is fastened to a base 52 to which the frame 15 is secured by means of a spacer 53 and fastener 54. This arrangement permits the various electrical connections to be provided in the margin of the panel 38 at spaced peripheral locations, such as illustrated in FIG. 3.

In view of the foregoing, it should be apparent that the present invention now provides an improved tactile sensor which is characterized by high resolution, sensitivity, durability and ready manufacturability.

While preferred embodiments of the present invention have been described in detail, various modifications, alterations and changes may be made without departing from the spirit and scope of the present invention as defined in the appended claims.

CLAIMS

1. A tactile sensor for converting a mechanical input into an electrical output, comprising:

a resilient platen having upper and lower surfaces;

a plurality of laterally spaced pressure sensing sites underlying said lower surface;

at least some of said pressure sensing sites including emitter means and companion collector means surrounding said emitter means in spaced relation therewith; and

flexible conductive means on said lower surface of said platen overlying said pressure sensing sites and cooperable therewith when said platen is deflected downwardly against a selected site to receive current emitted from said emitter means and to conduct to said companion collector means substantially all of the current flowing into the conductive means from said emitter means.

2. A tactile sensor as claimed in claim 1 wherein the emitter and collector means are in the form of electrodes and said flexible conductive means includes a plurality of conductive microprotrusions on said lower surface cooperabl with said platen to provide decreased resistance in response to increased downward pressure between said platen and said lectrode means.

3. A tactil sensor as claimed in claim 1 or claim 2 wherein said platen includes an electrically non-conductive elastomeric member and said conductive means includes electrically conductive particles distributed in an elastomeric carrier.

4. A tactile sensor as claimed in any one of the preceding claims wherein the emitter and collector means are in the form of electrodes and including means electrically connecting said emitter electrode means together in laterally spaced rows, means connecting said collector electrode means together in laterally spaced columns disposed at an angle to said rows, and panel means mounting said rows and columns and electrically isolating the same from one another both laterally and in the direction of pressure application.

5. A tactile sensor as claimed in anv one of the preceding claims including multiplexing circuit means adapted to be connected to the emitter electrode means for applying thereto in a selected one of said sites a positive voltage potential and for simultaneously applying a lower voltage potential to its companion and adjacent collector electrode means.

6. A tactile sensor as claimed in any one of the preceding claims including means for mounting at least a pair of the current collector means in laterally spaced el ctrically insulated relation to define through said flexible conductiv means a higher resistance to

current flow between the emitter means of one of the pair and the collector means of the other of the pair and between the other emitter means and the one collector means than provided between either current emitter means and its companion current collector means.

7. A tactile sensor as claimed in any one of the preceding claims wherein at least some of the emitter means includes a series of emitters arranged in a predetermined pattern and the respective current collector means surrounds each of said current emitters in said pattern.

8. A tactile sensor as claimed in claim 4 wherein said columns are circular and said rows are disposed radially with respect thereto.

9. A tactile sensor as claimed in claim 6 wherein said collector and emitter mounting means includes an electrically insulated panel extending along said platen in parallel relation.

10. A tactile sensor for converting applied pressure into an electrical signal, comprising:

an electrically substantially non-conductive elastomeric member having a top surface adapted to contact an object and a bottom surface;

a flexible conductive layer on said bottom surface providing a plurality of microprotrusions transverse thereto, said conductive layer

pr viding a porti n of a circuit having an electrical resistance which varies inversely with pressure applied transversely thereto;

an electrically insulated panel underlying said elastomeric member and having a topside and a bottom side;

a first series of current emitter electrodes mounted in spaced relation in a first column on the topside of said panel;

at least a second series of current emitter electrodes mounted in spaced relation on the topside of said panel in a second column extending alongside said first column;

a first current collector means mounted on said panel in said first column and surrounding each of said emitter electrodes in said first column in coplanar relation therewith;

at least a second current collector means mounted on said panel in said second column and surrounding each of said emitter electrodes in said second column in coplanar relation therewith;

each of said emitter electrodes in said first and second columns being spaced laterally from their respective first and second collector means to provid electrical insulation therebetween;

said first current collector means being spaced laterally from the second current collector means to provide electrical isolation therebetween;

means disposed in spaced rows on the underside of said panel transverse to said columns for supplying current to said current emitter means in said columns; and

frame means mounting said elastomeric member and panel in parallel relation with said emitter and collector means engaged with said conductive layer;

whereby current supplied to each current emitter flows transversely into the conductive layer, laterally therethrough, and transversely into its companion current collector when pressure is applied to the elastomeric member superadjacent thereto.

11. A tactile sensor as claimed in any one of the preceding claims wherein the flexible conductive means includes one or more of the following features: an asperity on its bottom surface providing microprotrusions; a continuous coating of electrically conductive elastomeric material and/or includes soft natural rubber and the coating is an electrically conductive polyurethane having a thickness of less than about one mil.

12. A tactile sensor according to any one of the preceding claims wherein each of said collector means

continuously surrounds but is spaced from its associat d emitter means.

13. Apparatus for use in providing a machine image of an object, comprising:

means providing a plurality of closely-spaced pressure sensing sites;

each of said pressure sensing sites including:

a current emitter electrode, and

a companion current collector electrode surrounding and spaced from said emitter electrode,

means electrically connecting a series of said emitter electrodes together in a row;

means electrically connecting an array of said current collector electrodes together in a column disposed at an angle to said row;

said emitter and collector electrode connecting means each being arranged with like rows and columns of connecting means;

a resilient platen having a topside adapted to contact an object and an underside with a rough flexible electrically conductive layer engaging said emitter and collector electrodes;

said layer providing along the platen between one emitter electrode and its companion collector electrode a resistance which is less than the resistance between said one emitter electrode

and adjacent non-companion collector electrodes;

means for applying to the current emitter electrodes in a selected row a predetermined positive voltage potential and for simultaneously applying to said current collector electrode in a series of selected columns a lower voltage potential to cause current to flow through the layer from the emitter electrode to the collector electrode whereat the layer is compressed in a magnitude related to pressure applied to the layer;

multiplexing means for effecting said voltage application in a predetermined sequence among said columns and rows and for monitoring said current flow in a selected one of said columns for providing a readout of the location of the applied pressure among said pressure sensing sites;

whereby both the location and magnitude of pressure applied to the platen by the object can be determined.

14. A method of sensing pressure at a selected one of an array of sites, comprising the steps of:

applying at the selected site a positive voltage to emit current into a pressure responsive conductive layer of a resilient platen overlying said array of sites;

flowing said emitted current outward from said

site and through said layer;

collecting substantially all of said current in said layer in a continuous region surrounding said selected site; and

monitoring said collected current to produce a readout of the applied pressure;

whereby the electrical activity within the layer is restricted to that portion of the layer immediately adjacent to the area of pressure application.

15. A method of producing a machine readable image of an object, comprising the steps of:

applying pressure to the object with a sensor having a resilient platen with a pressure responsive conductive layer contacting a series of current emitter electrodes electrically connected in laterally spaced rows and surrounded by spaced current collector electrodes electrically connected in laterally spaced columns providing an array of sensing sites;

applying to a selected one of said current emitter electrode rows a predetermined positive voltage potential and simultaneously applying to said collector electrode columns a lower voltage potential for causing current to flow from on emitter electrod in said selected row and through said layer only to an

immediately adjacent current collector electrode in a selected column;

collecting substantially all of said current flow from said collector electrode of said selected column; and

repeating said voltage applying step periodically among said rows and columns and periodically repeating said current collecting step among selected ones of said columns to provide an electrical output related to the shape of the object and the pressure with which it engages the platen.

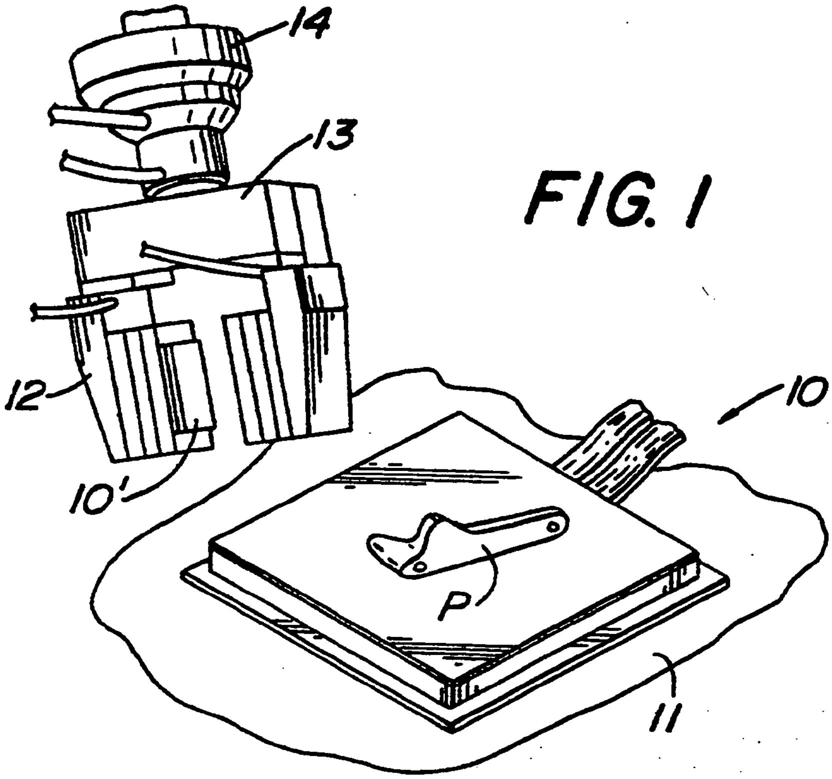


FIG. 1

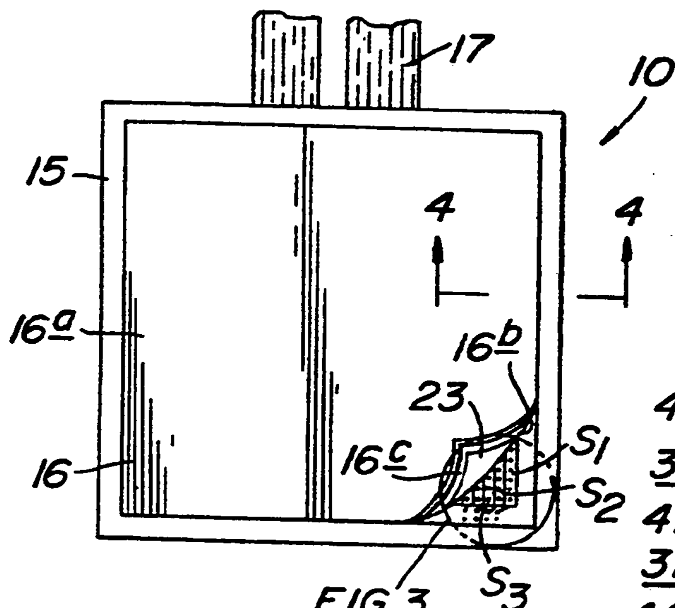


FIG. 2

FIG. 3

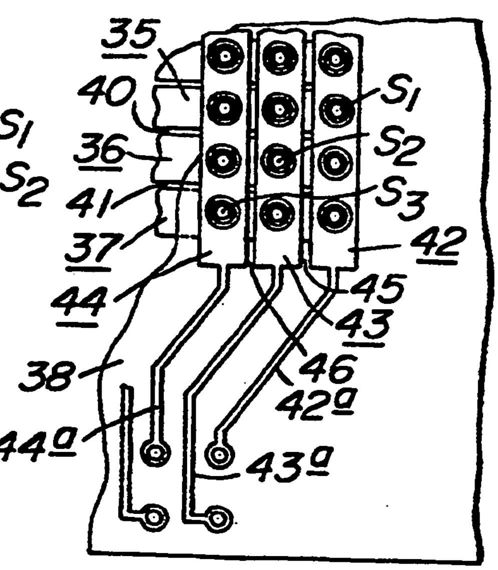


FIG. 4

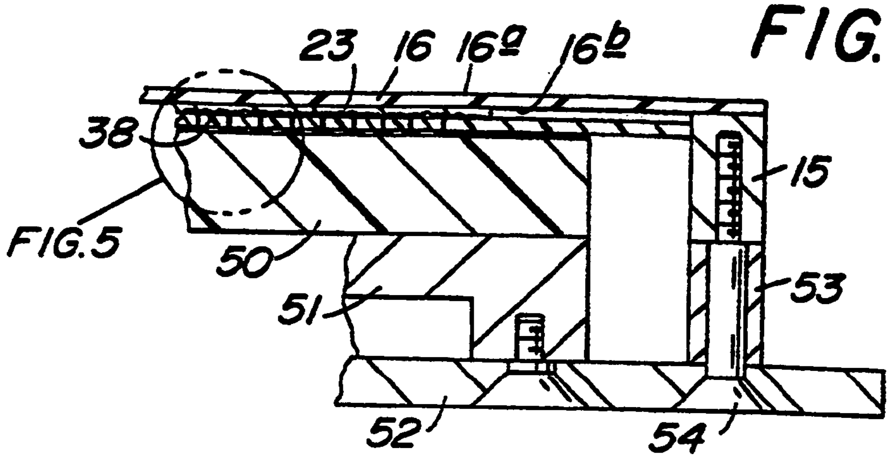


FIG. 5

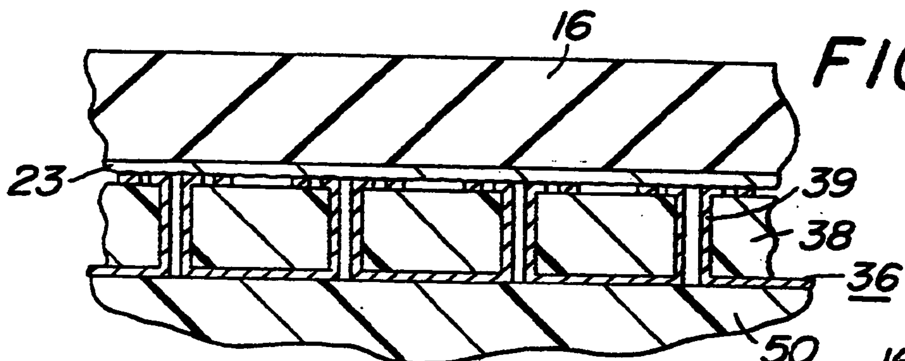
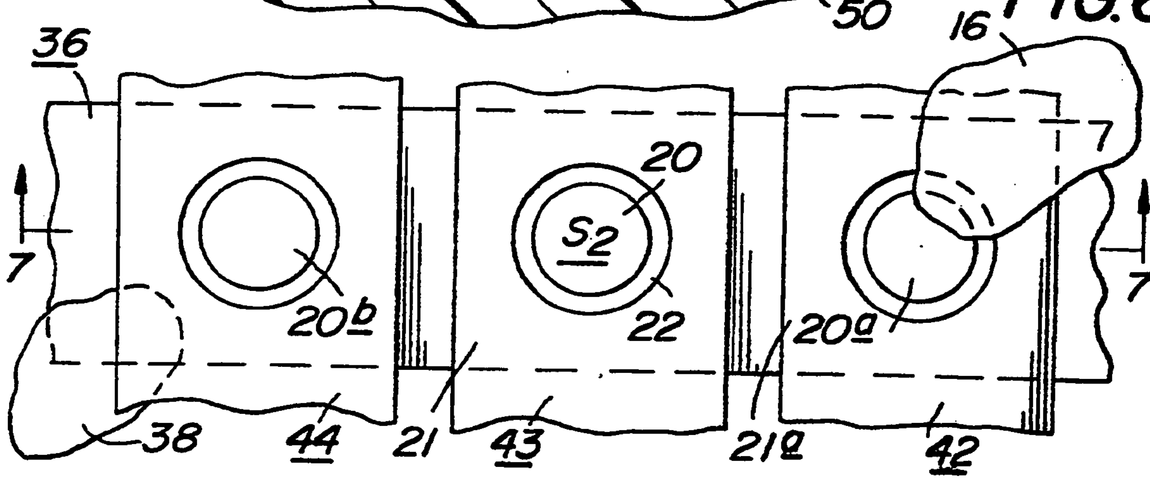


FIG.6



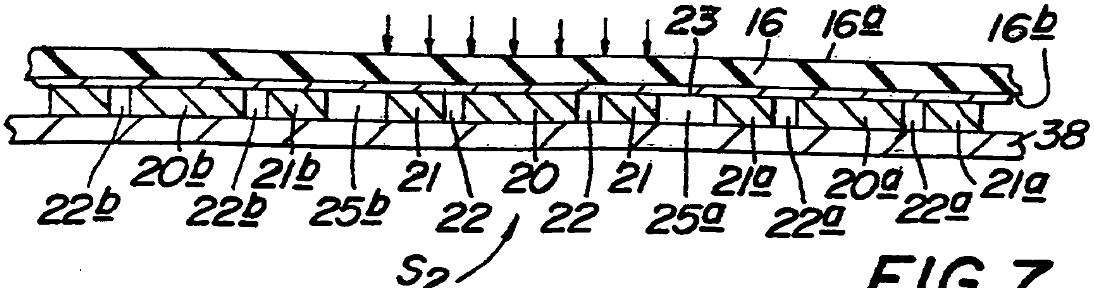
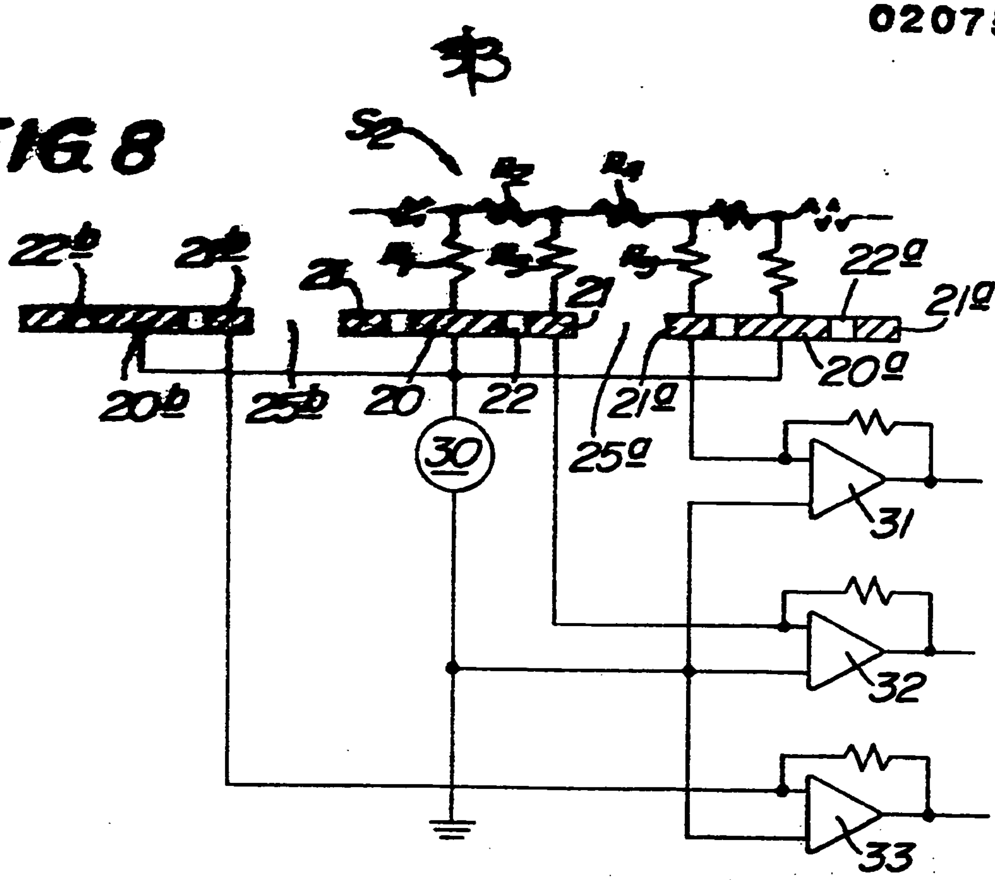


FIG. 7

FIG. 8



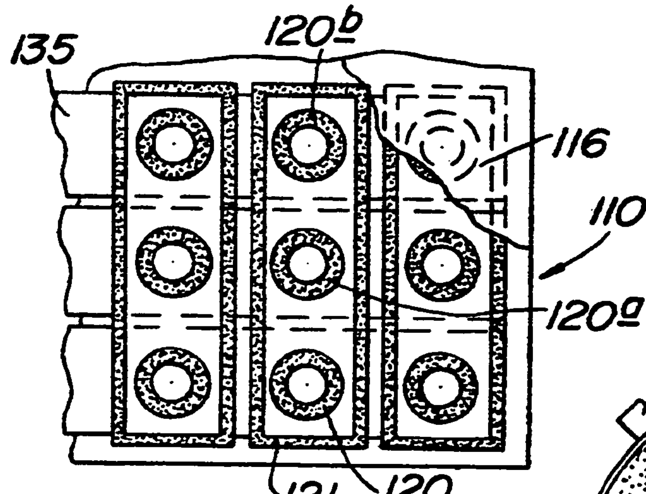
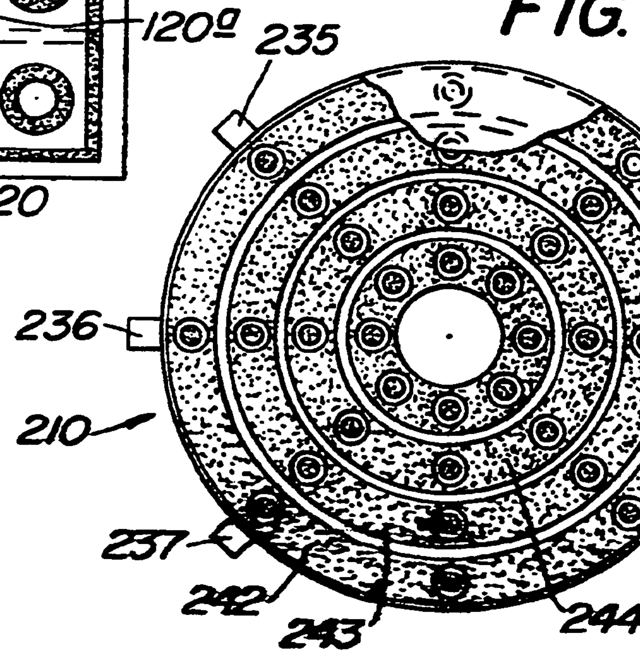


FIG. 9

FIG. 10



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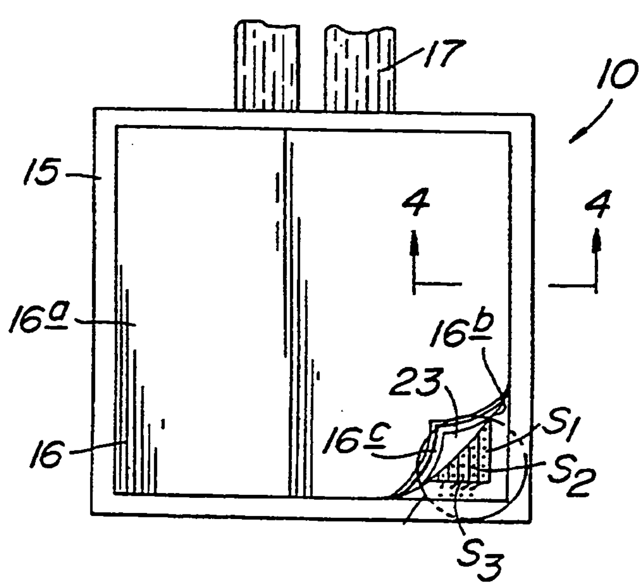
(74) Representative: Dunlop, Brian Kenneth Charles et al, c/o Wynne-Jones, Lainé & James 22 Rodney Road, Cheltenham Gloucester GL50 1JJ (GB)

(54) **Tactile pressure sensor.**

(57) A sensitive, durable, high resolution tactile sensor (10) particularly suited for use as a robot end effector in an automated manufacturing process. The tactile sensor (10) has an array of pressure sensing sites (S1, S2 . . .) provided by a series of current emitter electrodes (20) surrounded by a series of companion current collector electrodes (21) both of which engage a rough conductive layer (23) carried on the underside of a resilient platen (16). The emitters (20) are electrically connected together in parallel rows, and the collectors (21) are electrically connected together in parallel columns above and across the rows. The emitters (20) and collectors (21) are electrically insulated from one another as are the rows and columns. When the platen (16) engages an object (P) to apply pressure at one of the sites, and a positive voltage is applied to an emitter electrode, current flows from the emitter electrode (20) and through the conductive layer (23) to the companion collector electrode (21) from which it is collected and measured. Cross-multiplexing circuitry (36 etc) scans the rows and columns periodically to provide a readout of both th location and magnitud of applied pressure.



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EUROPEAN SEARCH REPORT

EP 86 30 1129

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
Y	GB-A-1 541 566 (SECRETARY OF STATE FOR DEFENCE) * Page 3, lines 9-82; figures 2,3 * ---	1-4,7, 9-15	G 01 L 5/22 G 01 L 1/20 G 06 K 11/06
Y	MESURES, REGULATION, AUTOMATISME, vol. 44, no. 5, May 1979, pages 19,21,23,25, Paris, FR: "Les caoutchoucs conducteurs sensibles a la pression pour certains claviers de commutation" * Figures 7,8 * ---	1-4,7, 9-15	
X	IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, vol. IM-27, no. 1, March 1978, pages 94-99, IEEE, New York, US; W.E. SNYDER et al.: "Conductive elastomers as sensor for industrial parts handling equipment" * Page 94, right-hand column, part B; figures 1-3 *	1,3,4, 7,9,10 ,12,14	**TECHNICAL FIELDS SEARCHED (Int. Cl.4)** G 01 L 1 G 01 L 5 G 06 K 11 H 01 C 10
Y	IDEM	2,11, 13,15	
A	IDEM --- -/-	5	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	26-02-1987	VAN ASSCHE P.O.

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
D,Y	US-A-4 014 217 (J. LAGASSE et al.) * Abstract; column 4, lines 54-68; column 5, lines 1-29; figures 1,2 * -----	1-4,7, 9-15	

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